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Franklin Mead and Bill Larson (AFRL/PRSP), "Measurement and Control of the Properties of Gases
Produced by Ablation of Delrin (Polyformaldehyde) with a CO₂ Laser "

Statement of Work (SOW) for EOARD Contract with
The Institut Für Technische Physik, DLR, Stuttgart, Germany (Deadline: N/A)

(Statement A)

**STATEMENT OF WORK (SOW)
FOR EOARD CONTRACT WITH
THE INSTITUT FÜR TECHNISCHE PHYSIK, DLR
STUTT GART, GERMANY**

***Measurement and Control of the Properties of Gases Produced by
Ablation of Delrin (Polyformaldehyde) with a CO₂ Laser***

OBJECTIVE: The primary objective of this research is to enable control of the properties of gases that are produced by ablation of solid Delrin with a pulsed CO₂ laser. Target gas properties are (1) a specific energy content greater than 100 MJ/Kg, (2) a specific impulse range from 200 to 800 seconds, and (3) an overall conversion efficiency of laser energy to jet kinetic energy of at least 50%.

TECHNICAL APPROACH AND METHODOLOGY: The absorption depth of infrared radiation in a solid polymer formulation may be reduced to an arbitrarily small value by increasing the dipole strength of the polymer with a small concentration of metal dopant (Ref. 1). The amount of polymer ablated by a laser pulse of given energy, and the specific energy content of ablated gases, may be controlled by adjusting the quantity of fine metal powders, fibers and/or spheres that are embedded in the polymer. The best candidate polymer is one that is easily atomized to a low molecular weight gas but is not easily ionized. Fully atomized Delrin [or polyformandehyde, (H₂CO)_n] has a molecular weight of 7.5 g/mol. The best metal dopant is one that will, in small concentration, produce large effective dipole strength, e.g., silver, iron, and the light alkali metals, lithium or sodium.

When a properly doped polymer absorbs an impulse of laser energy, a high velocity jet normal to the polymer surface is produced. Jet properties may be measured and quantified in terms of (1) specific internal energy of ablated polymer (energy per unit mass), (2) specific impulse of the jet (impulse per unit mass of ablated polymer), (3) coupling coefficient (impulse of jet per unit laser energy), and (4) overall energy conversion efficiency (jet kinetic energy per unit laser energy). Measurement of the laser energy with a calorimeter, the ablated polymer mass by weighing before and after ablation, and the jet impulse with a ballistic pendulum, allows the overall efficiency of conversion of laser energy to jet kinetic energy, the specific impulse, and the coupling coefficient to be extracted (Refs. 2-7).

Ablation experiments with measurement of ablated mass, impulse, and laser energy need be carried out using selected polymer/metal dopant formulations with appropriate geometries that provide a reasonable expansion ratio of around 15 for good internal energy to jet kinetic energy conversion (e.g., around 40% to 50%). An open paraboloidal cavity with polymer placed near the focus is one geometry that is easily subjected to thermodynamic idealization that enables establishment of an upper energy conversion limit based on isentropic expansion. The selected polymer formulations will need to have good mechanical strength and must produce clean ablation without fragmentation when subjected to laser pulse intensities in the range of 5 to 10 MW/cm², with fluence around 5 to 50 J/cm², and laser pulse widths ranging from 0.1 to 10 microseconds. Shorter pulse widths enable energy deposition into the polymer before gas expansion begins. Thus the heated polymer may be confined by its own inertia so that hot gas at densities near that of the solid are produced, around 1500 Kg/m³, which translates to effective combustion chamber pressures of around 1,000 bar.

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EXPECTED RESULTS: This project will accomplish the basic research on parameterization of laser characteristics (pulse energy, fluence, intensity, and repetition rate) and their optimization against absorption depth, polymer composition, specific internal energy, specific impulse, and energy conversion efficiency.

It is expected that the absorption depth will be reducible to around 1 micrometer, which, with reasonable laser intensities, translates to enormous internal energy capabilities ranging from 100 to 1,000 MJ/Kg in the ablated gases. At the extremely high pressures produced in the inertially confined gas, expansions with specific impulse values of up to 1,000 seconds should be achievable. The important result will be the elucidation of the methodology and polymer formulations for producing controllable specific impulse values between 200 and 800 seconds.

RATIONALE FOR CONDUCTING INTERNATIONAL RESEARCH

Unique Facilities: The high power pulsed CO₂ laser and vacuum chamber available at the DLR-German Aerospace Facility offer an uncommon combination of experimental research facilities and a co-located, seasoned research team. This combination has been responsible for demonstrating the performance of two laser propulsion concepts under simulated altitude conditions from sea-level to space. The DLR is a major Air and Space Research and Technology Development Organization in Germany with a huge cadre of scientists, engineers and technicians offering the critical mass and depth of knowledge and experience necessary for high efficiency productivity in a myriad of propulsion related disciplines. Although similar facilities exist in the U.S. (e.g. LHMEF facility at WPAFB) there is no place within CONUS where the experienced researchers and the facilities are co-located.

Unique Research Experience: Wolfgang Schall, research director of prior contracts, and his team of about six senior researchers and technicians have demonstrated a stellar performance record under the 2-year EOARD sponsorship of previous laser propulsion research. The research proposed here is an obvious extension of the German's previous research. During this proposed research they will need to solve the critical issue of increasing the specific impulse of laser ablated gases.

Significantly higher return on investment: The DLR has already demonstrated its support of this project by 100% cost matching for the 2-year laser propulsion program that EOARD previously supported. It is likely that additional cost sharing by DLR will be forthcoming. This project may stimulate additional German investment in laser interaction with materials research that far exceeds the cost of this proposal.

Other Rationale: Dr. Mead and Dr. Larson met with Wolfgang Schall at the International Symposium on Beamed Energy Propulsion and specifically discussed (for about 4-hours) plans for this research via an EOARD contract. Schall and his team are ready to begin this project immediately. Recent discussions with Dr. Ingrid Wysong (EOARD) in Reno during the recent AIAA meeting provided an opportunity to plan the initiation of this work by coordinating the approval process through AFRL/PRS and AFOSR more or less simultaneously in order to shorten the initiation time. Also, Dr. Wysong will be searching for funds during the approval

process to accomplish this work. Also note that the flow of information is strictly from the DLR to the AFRL.

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